DEVELOPMENT OF MANAGEMENT INFORMATION SYSTEM FOR TOOL PLANNING AND CONTROL

by

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INDUSTRIAL AND MANAGEMENT ENGINEERING PROGRAMME

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DEDICATED TO

MY PARENTS

CERTIFICATE

This is to certify that this work entitled " DEVELOPMENT OF MANAGEMENT INFORMATION SYSTEM FOR TOOL PLANNING AND CONTROL ", by Mr. N. Kishan, has been carried out under my supervision and that it has not been submitted elsewhere for the award of a degree.

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Nama Kishan

CONTENTS

ABSTRACT

Tool mananement is very critical for effective and uninterrupted operation in any production system. Tool managemen is mainly concerned with tool planning i.e., selection of tool and cutting conditions with the objectives of minimizing the cost of manufacturing operations and maximizing the rate of production for a given part design and manufacturing specification and machin tool characteristics, and tool control with the objectives of making available the right type of tool on the machine at righ time while keeping the overall investment in tools a minimum.

In the present thesis, several aspects of tool planning an control have been studied. Tool planning program can handle th machining operations like turning, boring, facing, taper turning thread cutting, planing, shaping, slotting, peripheral milling face milling, drilling and reaming for both deterministic an probabilistic cases. The tool life is considered as stochasti phenomenon for obtaining realistic results. The information syste developed for tool control supports the assigning of tools t various operations, procurement and replacement of tools scheduling the regrinding of tools for various needs.

The tool planning program written in Turbo Pascal and toc control system developed in dBase III plus is implemented on I XT/AT.

CHAPTER I

INTRODUCTION

1.1 Tool Management

Management of tools in production system is one of the important aspects like production management, inventory management, materials management, quality management and so on. However, little attention has been given to tool management in terms of academic research. This is due to the fact that investments in tools are relatively low. The recent developments of automated and capital intensive machine tools have imposed a severe requirement on utilization of these equipments. Therefore, it has become essential to plan and coordinate manufacturing activities so that the idle time on machine tools is minimum. Tools, although relatively less expensive, play a vital role in the utilization of machine tools. Thus, it is quite in order to study the various aspects of tool management like other management functions in a production system.

Major objective of tool management is to ensure that right kind of tool is available on right machine tool at the right time. It involves planning, procuring, storing, assigning and monitoring throughout the manufacturing process and finally disposing off the worn out tools. It also plans for the regrinding of the tools where ever applicable.

The Management Information System is defined as an integrated, user-machine system for providing information to

support operations, management, and decision-making functions in an organization. The system utilizes the computer software; manual procedures; models for analysis, planning, control and decision making; and a database. [5]

In the present work, two important aspects of tool management viz., planning and control are considered. The management information system is developed for these management functions.

1.2 Tool Planning and Control

The tool planning and control is concerned with tool type selection for a given set of machine tool types and products depending on their configuration, manufacturing specifications and the batch size.

Tool type selection involves selecting the type of tools to be used for the operations and is done based on the requirements of surface finish, type of operation, and technological constraints such as maximum force limit, speed, feed rate, depth of cut and power constraints of machine tools and managerial constraints such as production rate, production cost, profit etc. Batch size gives the number of jobs to be scheduled in a given time. This gives the information about the production rate. The machine tool type is selected based on the production rate, quality characteristics of the product and machine tool capabilities.

The selection process is carried out by obtaining the information from Machine and Tool Databases. The tool database contains the information about tool characteristics, tool life, tool cost. Machine database consists of machine tool characteristics such as machining cost, the constraints on the

cutting parameters etc.

The next step is to determine the sequence of operations. The process planning undertakes the task of determining the sequence of operations, setting time standards, cutting conditions. Even if we know the set of tools and machine tools, which can be used for particular operation, we sometimes are not free to choose any tool or machine tool since tools selected for that particular operation may not turn out to be optimal.

The production schedule is a Gantt chart or machine/job sequence giving the start times and due dates for the operations. Production schedule is prepared after performing process planning. The input to the production scheduling are process planning and batch size. A single tool may not be able to serve all the units in a batch because of its life constraint. A tool is sent for regrinding after its life is over and to undertake remaining operations, a new tool of same type is brought in. Batch size thus gives an idea of the requirement of the number of tools of same type.

Tool control is carried out as the next step. The input to this decision function is Gantt chart from production scheduling and information from tool database. To make the right type of tool available on machine at the right time, the tool life monitoring is to be done. For monitoring the tool life, one of the most popular criterion is the flank wear on the tool. The amount of wear caused at the flank for each operation depends on the time of operation and the cutting conditions. When the life of tool (maximum possible regrindings) is over, then tool is scrapped, and new tools are procured.

1.3 Tool Life

Tool life is one of the important ingrediants in tool planning and control. It was deterministically described by Taylor in 1909 as

$$V\, T^{n} = C$$

and updated to truer forms by host of authors with expressions such as

$$T = A\, V^{-B}\, f^{-C}\, d^{-D}$$

where,

V = speed,

f = feed rate,

d = depth of cut,

n = exponent to tool life

C, A = constant,

B, C, D, = exponents to speed, feed rate, depth of cut.

However, this is still a deterministic description of what is known as a slow death mechanism of tool failure. The life of tool is terminatd in many different ways and by many different causes. Tool life, T, under these complex cause-effect systems full of uncertainties is regarded as a random variable.

Tool failure can be characterised by

(i) Slow death (wear failures at the flank and crater as well as the nose radius and the outer diameter groove);

(ii) sudden death (fracture due to overload or tool softening, chipping of the edge due to brittle tool materials, faulty design, interrupted cuts etc. and even low cycle fatigue caused by thermal shock and/or impacts during interrupted cutting);

(iii) Accelerated death.

The latter mode is quite complex but it basically suggests the tool died from complications that developed during the operation. Accelerated death involves the interaction of the casuality functions resulting in a more rapid death that would have occurred from either cause individually.

In production environment, tool life is the economical useful life of a cutting tool before reconditioning or replacement. The units in which tool life is measured vary according to the manner in which the tool is used. It may be measured in number of tasks completed (e.g., holes drilled) or integral pieces produced under specified cutting conditions (e.g., feed, speed, depth of cut, etc). Tool life may also be measured in machining time units, volume of material removed or surface area machined.

Tool is no longer useful when it loses its ability to cut to specifications including geometric tolerance, surface roughness and established limits on cutting forces. The useful tool life for the same tool and operations may be longer if the tool is used on a different machine with greater tool offset, rigidity or load bearing capacity. Such variations between machines must be considered while designing control strategies, computer tool monitoring, and replacement strategies.

If the extent of progressive tool wear governs the useful tool life, then monitoring the cutting forces, surface finish, and size of workpiece can provide indications of the succesful operation within predetermined performance limits. Sensors data can be used in real-time to compensate for tool wear by changing tool offset. However, the work piece size and surface finish

indicators of tool wear do not provide an early enough warning when tool failure is caused by fracture. Although the effect of tool breakage on cutting forces is measurable in real time, damage avoidance depends on the ability of the machine to quickly reduce feed, stop spindle or withdraw the tool.

Since today's sensing technology does not provide a complete, reliable and economical solution to the tool monitoring and failure detection problems, a rather conservative and deterministic approach is used in the production environment to define useful tool life. Such safe and methodical strategies for tool replacement, well before any damage to the workpiece or machine is likely to happen, do not optimize tool or machine utilization. Therefore, enhancing the capabilities of the machine to enable it to detect and respond to all modes of tool failure increases productivity by utilizing a larger portion of the total tool life.

Attempts to develop analytical methods for predicting tool failure have not been very successful. This is mainly because the tool failure phenomenon is probabilistic in nature and failure mechanisms are not yet fully understood. Infact, the random aspects of the tool life must also be considered to provide some what more completeness to the phenomena.

1.4 Deterministic and Stochastic Systems

The variables of stochastic system are random in nature, that is, their value can only be guessed. The practical value of theory lies in its predictive value. Good theories must be able to predict what will happen under different circumstances and thus answer "what-if" questions. They must also be able to predict what

will happen in future. Theories, which can not make predictions may be of intellectual or aesthetical value, but they have no practical use while solving real life problems.

The very definition of randomness implies that individual random phenomena are unpredictable. The introduction of probabilities does not invalidate this statement.

In stochastic systems, it is impossible to predict the behavior of the system at a time t. Only averages and frequencies at which the variables of the system assume certain values can be predicted.

In determistic systems, the state variables are defined to be the set of variables that jointly allow us predict the future value of any variable in the system. For stochastic systems, this definition is not applicable because the system variables are not normally predictable. The state variables are therefore the set of variables that jointly determine the distributions of the future values of all system variables. The system varibles include, of course, all the variables of the system, whether they are state variables or not.

In a typical stochastic system, the system variables have an irregular pattern.

Stochastic systems usually do not reach an equilibrium in a deterministic sense, that is, the state variables do not normally reach a constant value. It is entirely possible, however, that the averages of state varibles and their distributions reach an equilibrium.

Most of the authors considered tool life deterministic but in actual practice, it is probabilistic since the conditions of

cutting can not be maintained absolutely similar, the conditions under which tools are manufactured also vary and we can not expect all tools having similar microstructure or material type. So it is justified that tool life should be considered probablistic.

These concepts of determistic and stochastic systems are of utmost importance in the context of tool planning and control specifically while modelling the tool life. Some of these points are described in the following section.

1.5 Literature Review

The bulk of research on machining economics has been concerned with finding the optimum based on a deterministic tool life concept. The tool life, however, is a statistical quantity and the nature of its probability distribution has been investigated by various researchers [18,19,23,29]. Results obtained, using the deterministic tool life concept, may serve well as approximations but these results can be substantially different from the actual optimum.

Schmidt [24], generated the tool life data and showed that the assumption of lognormal distribution to model tool life/death adequately represents many practical situations.

Data published by the National twist drill company [17], for drilling of alloy steel with high speed steel tool again gives an excellent fit to a lognormal distribution. Here tool life is measured as the number of holes drilled per tool.

In a single point turning of low carbon steels by high speed steel tools, Wager and Barash [26], obtained data which fits a lognormal distribution quite well.

Ramalingam and Watson [18], showed that the tool life is

given by Weibull distribution (one class of hazard only) for single injury failure model, by hazard function concept. This distribution is valid for both time dependent and time independent failure hazards.

Same authors [19], showed that for multitude of injuries the tool wear process leads to gamma distributed tool-life density distribution function. It is shown tool wear may well be lognormal if the tool failure is due to crater formation and growth in nonlinear wear region.

The economic mathematical models for the different operations of metal cutting have been formulated by many investigators such as Field [10,11] et al. The objective functions of these models are cost of production per piece, production time, or a weighted combination of both, which is the most practical objective. In these models the cutting conditions, namely cutting speed, feed rate, depth of cut are considered the optimization variables. The optimization problem is restricted or constrained by some variable bounds, and operation constraints. In this model, Taylor's tool life equation is used. In order to use the generalized equations of cost and production rate, it is necessary to have available pertinent tool life data for each of the tools.

Abuelnaga and El-dardiry [1] formulated the general optimization problem and surveyed most of the available computer optimization codes, which have been used for metal cutting operations and discussed advantages and drawbacks of these methods.

Ermer [8] has used the geometric programming (GP) for the optimization of the machining operations for deterministic case

only. The same author [7], using the same technique, showed that multipass turning is optimum. He showed that two passes or some times three passes can be cheaper or take less production time and found the ratios of rough to finishing depth of cut. GP is capable of serving certain problems involving nonlinear terms in both the objective function and constraints. GP finds the optimum of the objective function first, instead of seeking the optimum values of the optimization variables for the optimal cost.

Iwata et al [15] used continuous dynamic programming method for the optimization of cutting condition for multipass operations, where a given total depth of cut is to be removed from a workpiece. He assumed that the number of passes in metal cutting corresponds to the number of decision stages in dynamic programming and the cutting conditions at each pass correspond to the stage decisions at each stage. The stage state is the diameter of the workpiece at each stage. The decision variables speed, feed rate and depth of cut at each stage are found for probabilistic nature of objective function and constraints in the machining process.

Dynamic programming is an optimization method used for making a series of interrelated decisions, which starts with a small portion of the problem and finds its optimal solution. Then gradually enlarges the problem, finding the current optimal solution from the previous one, until entire problem is solved. In continuous dynamic programming the optimization variable can take on any real value. If only few variables are involved or the problem is small, other methods are more efficient.

Hati and Rao [12,20], used sequential unconstrained

minimization technique (SUMT) for the determination of optimum machining conditions in different operations for both deterministic and probabilistic methods.

Iwata et al., [14], employed SUMT combined with Newton Rapson method to determine the optimum cutting conditions considering the probabilistic nature of the objective function and constraints applying chance-constrained programming concept.

Imo and Leach [13], used SUMT successfully for a class of production problems which involve nonsmooth, discontinuous functions. These functions are modified to suit the applicability of SUMT.

The SUMT developed by Fiacco and McCormick, uses the problem constraints and original objective function to form an unconstrained objective function which is minimized by any appropriate unconstrained, multivariable technique, where several options are available. In this method, the objective function is modified by adding severe penalty to it, whenever a constraint is violated in such a way that the unconstrained optimization technique is forced to find minimum in a feasible region. The same technique is used in the present work.

McCartney and Hinds [16], developed a procedure in which selected jobs, initially programmed in a schedule at maximum production rates have their machining rate reviewed in order to reduce costs. They assumed an integrated manufacturing system with a job shop work pattern in which due date criteria are applied to finished jobs. The cost reduction procedure is operated while maintaining original schedule performance.

Fenton and Joseph [9] developed computer program for

optimization assuming that tool life has probability distribution of normal, uniform and Weibull type. They suggest that if the nature of statistical distribution of tool life is not known, it can be estimated using experience. They recommend Weibull distribution with shape factor of 1, if no information is available regarding tool life distribution.

Wysk et al., [28], presented the optimization of cost and rate with lot size consideration and only single decision variable (speed).

By applying the fundamental economic principle that maximum profit occurs when the marginal revenue equals the marginal cost, Wu and Ermer [27], determined the optimum cutting speed for turning operation (without any constraint) to maximize the profit.

A tool information system based on database is developed by Gopinath [25] for the use of various functions of manufacturing system, namely, 1) Part Programming, 2) production Planning, 3) Process Planning, 4) Process Control 5) Tool Maintenance, and 6) Tool Stock Control.The various reports are generated for effective tool planning and Control.

1.6 Organization and Scope of Thesis

In the present thesis we shall deal with deterministic and probabilistic aspects of the tool life and optimization of machining condition. A database is developed for tool control.

Chapter II deals with tool planning aspects. The problem of optimization for machining conditions for deterministic and probabilistic cases, is formulated. Considering the probabilistic nature of tool life, distributions for single edge and multi edge tool are discussed. It also gives methodology used for estimating

tool life parameters and optimization of metal cutting processes.

Chapter III deals with the tool control aspects. It also discusses about real-time reports and tool status reports.

Chapter IV gives the process of implementation of optimization program in turbo pascal on PC/XT and tool control database in dBase III Plus. These two modules are connected by using batch files.

Chapter V gives the conclusions and scope for further work.

CHAPTER II

TOOL PLANNING

2.1 Introduction

For a set of operations to be performed on certain machine tools, tool planning involves selecting and assigning appropriate tools from the available set. In the first pass this may result in more than one technologically feasible tools for a particular operation. Final selection of the tool is made by considering the minimum cost and/or maximum production rate. Using the deterministic tool life, we get approximate values of speed, feed rate and depth of cut which are further investigated by using probabilistic tool life expressions. This also helps in estimating the mean and the standard deviation of objectives - production cost and production rate. As discussed in Section 1.4, the tool life is random phenomena so probability distributions are used in the optimization problem. Before formulating the Optimization problem, we discuss about tool life distributions.

2.2 Tool Life Distributions

Tool life is terminated by two basic models.

(i) Sudden collapse or accidental breakage, represented by constant hazard function for which exponential distribution is used.

(ii) Progressive tool wear, represented statistically by increasing hazard function.

Since the progressive tool wear is taken care by hazard

function increasing with time, this leads to either normal or lognormal distribution function. For normal, negative tool lives would be covered by left hand tail. In order to avoid the absurdity logarithmic transformation is advocated. However owing to sizable scatter typical of tool life testing, neither hypothesis could be disproved even in rather exhaustive tests, as the amount of information required to achieve enough power in the test for goodness of fit entailed excessive costs. Therefore, with obvious limitation of disregarding negative values, normal distribution can also be used as it does not conflict with available evidence. From theoretical point of view, normal distribution may even be preferred to lognormal, as while in the latter case the hazard function shows a maximum value, in the former it increases monotonically with tool life, a much more satisfactory behavior.

For more demanding operations, such as drilling, taping and whenever brittle tool materials are involved, other models are required. A Weibull distribution can successfully be adopted in an empirical model covering broad range of phenomena. Hazard function either increasing or decreasing with time (as well as constant) can be catered for due to the added flexibility provided by the presence of additional parameters. However there are limits to this model too, as the connection between machining parameters and tool decay is hard to set and theoretical validation is possible only in the limited frame work of fatigue phenomena.

2.2.1 Single Edge Tool Life Model

A statistics to tool life, based on the assumption that wear and fracture are the causes of tool death, can be derived as

following [18,19,22,23,29].

If $R_F(T)$ is used to indicate the probability that a sudden collapse will not take place during time T, and $R_W(T)$ for the probablity that the failure due to wear will not occur during the same period, assuming these two types of failures are essentially independent of each other, the cutting edge survival R(T) can be written in the form

$$R(T) = R_F(T)\, R_W(T) \tag{2.1}$$

Assuming breakage only distribution is exponential, wear only distributin is lognormal, Eq. (2.1) becomes

$$R(T) = \left[1 - \int_0^T \lambda\, e^{-\lambda t} dt \right] \left[1 - \int_0^T (\sigma t\sqrt{2\pi})^{-1} e^{-((\ln(t)-\mu)/\sqrt{2}\sigma)^2} .dt \right]$$

where

μ = Average of the logarithm of tool life (ln(t)) determined by wear only.

σ^2 = Variance of the logarithm of tool life (ln(t)) determined by wear only.

λ = Failure rate due to fracture only.

The expression for R(T) can be written as follows

$$R(T) = e^{-\lambda T}\left[1 - \int_{-\infty}^{u} 1/\sqrt{\pi}\; e^{-y^2}\, dy \right] \tag{2.2}$$

where,

$$y = \frac{\ln(t)-\mu}{\sqrt{2}\sigma} \quad \text{and} \quad u = \frac{\ln(T)-\mu}{\sqrt{2}\sigma} .$$

The Eq. (2.2) can be simplified as

$$R(T) = e^{-\lambda T}\left[1 - 0.5 - \int_0^u 1/\sqrt{\pi}\; e^{-y^2}\, dy\right]$$

$$= 0.5.e^{-\lambda T}\left[1 - \mathrm{erf}(u)\right].$$

where,

$$\mathrm{erf}(u) = 2/\sqrt{\pi}\int_0^u e^{-y^2}.dy\ .$$

Cumulative distribution function of tool life becomes

$$F(T) = 1 - 0.5\; e^{-\lambda T}\left[1 - \mathrm{erf}(u)\right].$$

Evaluation of Mean (μ_T)

The average life of cutting edge, μ_T is

$$\mu_T = \int_0^\infty R(T)\; dT. \tag{2.3}$$

Substituting R(T) from Eq. (2.2), we get

$$\mu_T = \int_0^\infty e^{-\lambda T}.dT - 1/\sqrt{\pi}\int_0^T e^{-\lambda T}\int_{-\infty}^u e^{-y^2}.dy. \tag{2.4}$$

Solution of first integral and exchange of the integration limits in the second enables Eq. (2.4), to be written as

$$\mu_T = \lambda^{-1}\left[1 - 1/\sqrt{\pi}\int_{-\infty}^{\infty} e^{-y^2}\; e^{-\lambda e^{(\mu+\sqrt{2}\sigma\pi)}}\; dy\right].$$

Let $a = \sqrt{2}\sigma$ and $b = \lambda e^{\mu}$.

The integral in the second member can be written as

$$I = \int_{-\infty}^{\infty} e^{-y^2} e^{-be^{ay}} dy. \qquad (2.5)$$

and solved by power series expansion, we obtain

$$I = \sqrt{\pi}\ e^{-b} \left(\sum_{n=1}^{\infty} \frac{a^{2n}}{(2n)!!} \cdot \frac{C_{2n}}{2^n} + 1 \right). \qquad (2.6)$$

where,

$$C_0 = 1.$$

$$C_{n+1} = -b \sum_{k=0}^{m} \binom{n}{k} C_k .$$

It follows that μ_T is given by the equation

$$\mu_T = \lambda^{-1} \left[1 - e^{-\lambda e^{\mu}} \left[1 + \sum_{n=1}^{\infty} \frac{\sigma^{2n}}{(2n)!!} \cdot C_{2n} \right] \right] . \qquad (2.7)$$

Evaluation of Variance (σ_T^2)

The variance of tool life is given by

$$\sigma_T^2 = 2 \int_0^{\infty} T\ R(T)\ dT - \mu_T^2 .$$

we can write,

$$\sigma_T^2 = 2 \left[\lambda^{-2} - 1/\sqrt{\pi} \int_0^{\infty} T\ e^{-\lambda T}\ dT \int_{-\infty}^{\frac{\ln(T)-\mu}{\sqrt{2}\sigma}} e^{-y^2}\ dy \right] - \mu_T^2 . \qquad (2.8)$$

Interchange of integration limits and integration by parts

enable Eq. (2.8), to be expressed in the form

$$\sigma_T^2 = 2\lambda^{-2}\left[1 - 1/\sqrt{\pi}\ I\right] - 2(\lambda\sqrt{\pi})^{-1}\int_{-\infty}^{\infty} e^{-y^2}\, e^{\sqrt{2}\sigma y+\mu}\, e^{-\lambda e^{\sqrt{2}\sigma y+\mu}}\, dy$$

$$- \mu_T^2 . \qquad (2.9)$$

where I is given by the Eq. (2.5) or Eq. (2.6).

Integration by parts of the second member integral in this equation gives

$$\sigma_{T^2} = 2\lambda^{-2}\left[1 - 1/\sqrt{\pi}.I\right] + 4\,(\lambda^2\sqrt{2\pi}\sigma)^{-1}\int_{-\infty}^{\infty} ye^{-y^2} e^{-\lambda e^{\sqrt{2}\sigma y+\mu}}\, dy$$

$$- \mu_T^2 . \qquad (2.10)$$

With $a = \sqrt{2}\sigma$ and $b = \lambda e^{\mu}$ as in derivation of μ_T, solution of double exponential by power series means that the second member integral in Eq. (2.10), can written as

$$J = \int_{-\infty}^{\infty} ye^{-y^2} e^{-be^{ay}}\, dy. \qquad (2.11)$$

$$= e^{-b}\int_{-\infty}^{\infty} ye^{-y^2}\sum_{n=0}^{\infty}\frac{(ay)^n}{n!}\, C_n\, dy.$$

$$= e^{-b}\sum_{n=1}^{\infty}\frac{a^n}{n!}\, C_n\int_{-\infty}^{\infty} e^{-y^2}\, y^{n+1}\, dy. \qquad (2.12)$$

where $C_n = -b\sum_{k=0}^{m}\binom{n-1}{k} C_k$.

Eq. (2.12), contains odd terms only. If we make $n = 2m + 1$, it can be transformed into

$$J = e^{-b} \sum_{m=0}^{\infty} \frac{a^{2m+1}}{(2m+1)!} C_{2m+1} \frac{\sqrt{\pi}\,(2m+1)!!}{2^{m+1}} . \qquad (2.13)$$

Since

$$\int_{-\infty}^{\infty} y^{2(m+1)} e^{-y^2} dy = \frac{\sqrt{\pi}\,(2m+1)!!}{2^{m+1}} .$$

This gives the following expression for σ_T^2

$$\sigma_T^2 = \lambda^{-2} \left[1 - 1/\sqrt{\pi}.I^2 + 4\ (2\pi)^{-1/2}\ \sigma^{-1}\ J \right]. \qquad (2.14)$$

2.2.2 Multi Edge Tool Life Model

A multi edge tool e.g. milling tool, may be regarded as a set of single-edge tools, all working under identical conditions. Such a tool can thus be compared with a system composed of elements to be arranged in series, in which the collapse of one element throws the entire system out of action.

Examination of a statistical life model for a multi-edge tool - the term life meaning the interval between breakdowns - must necessarily take into account the policy adopted for replacement of failed cutting edges. This can only take one of two forms.

a) Replacement of the complete tool when one cutting edge fails;

b) Replacement only of the edge failed.

Policy (b) clearly involves a statistical study - of the interval between the replacement and the next after the first replacement starting from the complete renewal of the tool. Moreover, the analytical difficulties are such as to justify computer simulation. This is still the only way of obtaining reliable information in a relatively simple manner when the

analytical approach is priced out of reach.

Only policy (a) is considered here. It will be evident that its study will also offer fundamental information on the statistics for policy (b) upto the moment of the first breakage. In such a case, T is equivalent to the shortest of the lives of all the single cutting edges i.e.,

$$T = \min.\ (T_1, T_2, \ldots, T_z)$$

where T_i is the life of the i^{th} edge ($i = 1,2,\ldots, z$).

If it is now assumed that the events causing the failure of each edge are independent of each other, and at any rate not mutually exclusive, the cumulative probability that the life of the tool will be between 0 and T is given by

$$F(T) = 1 - \prod_{i=1}^{z} R_i(T). \qquad (2.15)$$

where $R_i(T)$is the survival function of the i^{th} edge. The probability density function takes the form

$$f(T) = \sum_{i=1}^{z} f_i(T) \prod_{j \neq i} R_j(T), \qquad (2.16)$$

$$(j = 1, 2, \ldots, z)$$

where $f_i(T)$ is the density function of the i^{th} edge.

When all the cutting edges belong to the same population, Eq. (2.15) and Eq. (2.16) can be simplified to

$$F(T) = 1 - [R_1(T)]^z$$

$$f(T) = z\ f_1\ (T)\ [R_1(T)]^{z-1} \qquad (2.17)$$

where subscript 1 represents the statistical function of the single edge.

For multi-edge tools the hazard function is given by

$$f(T) \quad = \quad \frac{f(T)}{R(T)} = \frac{z \; f_1(T)}{R_1 \; (T)}$$

as the sum of the hazard functions pertaining to the each cutting edge.

If, it is assumed that life of an edge follows the Eq. (2.1)

$$R(T) = R_F(T) \; R_W(T)$$

the survival function will be

$$R(T) = [\; R_F(T) \; R_W(T) \;]^z$$

which gives

$$f(T) = - \frac{dR(T)}{dt} = z \, [\; R_F(T) \; R_W(T) \;]^{z-1} \, [f_F(T) \; R_W(T) + f_W(T) \; R_F(T) \;]$$

Then we get

$$\mu_T = 2^{-z} \int_0^{\infty} e^{-\lambda_z T} \; (\; erfc(u) \;)^z \; dT. \tag{2.18}$$

$$\sigma_T^2 = 2^{1-z} \int_0^{\infty} T \; e^{-\lambda_z T} \; (\; erfc(u) \;)^z \; dT - \mu_T^2. \tag{2.19}$$

where

$$erfc\;(u) = 2/\sqrt{\pi} \int_u^{\infty} e^{-y^2} \; dy.$$

Taking now for the use of a single edge a Weibull distribution, with probability density and survival function as

$$f_1(T) = \beta \; \rho \; (\rho T)^{\beta-1} \; e^{-(\rho T)^{\beta}}$$

$$R_1(T) \quad = e^{-(\rho T)^{\beta}}$$

where β and ρ are respectively the shape and scale parameters,

Eq. (2.15) can be written as

$$f(T) = \beta \rho' (\rho' T)^{\beta-1} e^{-(\rho' T)^{\beta}}$$

where the scale parameter ρ' is given by

$$\rho' = \rho z^{1/\beta}$$

The above equation shows that the tool life distribution is still a Weibull distribution with a scale parameter which increases with increasing values of z. The average tool life and tool variance take the form

$$\mu_T = \rho'^{-1} \Gamma(1+\beta^{-1})$$

$$\sigma_T^2 = \rho'^{-2} \left(\Gamma(1+2\beta^{-1}) - [\Gamma(1+\beta^{-1})]^2 \right) .$$

with $\Gamma(a) = \int_0^\infty y^{a-1} e^{-y} dy$.

So the survival function, for multi-edge tool, all other parameters being equal, will tend to decrease for a given T value as the number of edges increases. In other words the hazard function tend to increase.

Adoption of policy (a), is certainly mandatory or valid in two cases

(i) for integeral cutters, since resharpening edge whenever possible requires that of all the others.

(ii) when the cutting elements fail as a result of wear only.

Parameter Estimation

Parameter estimates may be derived from actual production data using information readily available.

Given a batch of tools discarded after service under given machining conditions, average life and variance of those worn out yield estimates of mean and variance while breakage rate may be roughly assessed by dividing the number of observed failures by breakage by the total cutting time of all tools in the batch.

Mean time between breakage-induced-failures follows directly. Sequential analysis of machining data may enable evolutive control and updating of the relevent information.

2.3 Evaluation of Mean and Standard Deviation of Tool Life

The mean and standard deviation of Tool Life discussed in Section 2.2, can not be found analytically. For finding them, the integrals I [Eq. (2.5)] and J [Eq. (2.11)] are evaluated by Monte Carlo method. Monte Carlo is the non-analytic technique to obtain approximate solutions of functional equations of various types such as definite integrals, integrodifferential equations, linear equations, complex systems without determination of the complicated analytical representations of the system. It is numerical method of solving non-deterministic (Stochastic) systems by random sampling.

For evaluating I or J, 100 samples of pair of uniform random numbers are selected within the bounds of function. Let each pair represent a point in XY-plane. Percentage of points in the 100 samples which fall under the curve of function (which is derivative of I or J) are found, which is the appropriate value of function I or J.

2.4 Formulation of the Optimization Problem

The importance of being able to select the economically optimum machining conditions has long been recognized in the metal

cutting field. The basic mathematical model which has been used in the analysis of machining economics is a unit-cost model, or an analogous unit-time model if costs are neglected. In conjunction with these models two criteria have been used in determination of the optimum cutting conditions, one is mimimum cost and other is maximum production rate.

However, this may not be the normal situation and cutting conditions are usually selected from the viewpoint of minimizing cost, under the assumption that operating at the minimum cost conditions will tend to increase profit in the long run. It has been recognized that between these two criterion there is a range of cutting conditions from which an optimum point could also be selected. So the appropriate weighing factors to total cost and production rate can be selected depending on the operation for application.

If the operation is bottleneck in production sequence, it must be necessary to operate at the cutting conditions for maximum production rate. If the cost involved is of the secondary importance or production cost is least effective for maximizing profit, production rate is only of prime importance.

The problem is formulated in different ways, taking into consideration constraints on cutting speed, feed rate, depth of cut, power and force requirements, and on the quality of surface finish produced. Different numerical methods are used in search for the optimum solution [7,8,10,12].

In order to obtain more realistic machining economic calculations should be based on statistical, instead of deterministic, concept of tool lives. The difficulty with the

probabilistic approach is that insufficient information is available regarding the nature of the statistical distribution of tool lives.

Inherent randomness in various elements constituting the above mentioned objectives turn the objective functions into a set of random variables. It is often difficult to characterize the distribution of these random variables.

Total machining cost per work piece, for ex., can be considered to be a function of speed, feed rate, depth of cut, cutting time, loading and unloading time, machining and tool costs and tool characteristics such as tool life is most dominating one in defining randomness in total cost. Similarly it also plays vital role in defining randomness in production rate.

The nature of the statistical distribution of tool lives are different for various tools, and it may even be different for the same tool working under different conditions. The probability density function of the distribution can, generally, be approximated with reasonable accuracy for the purpose of computation by the two different distribution functions as explained in Section 2.2.

In practice, metal cutting phenomenon are mainly probabilistic, and hence the coefficients involved in the equations and formulations of such phenomenon have a probabilistic nature, e.g., tool life and cutting force equations which are considered in establishing an objective function and constraints are probabilistic. The amount of tool wear varies from tool to tool due to inherent variations in the tool wear mechanisms along with experimental variations. Thus the tool life estimated from

tool wear observations should be treated as a random instead of a deterministic variable. The coefficients in an experimentally determined cutting force equation should also be treated as random variables.

First we consider the formulation of Deterministic Model and then the Probabilistic Model.

2.4.1 Deterministic Model

The problem of determining the optimum machining conditions can be formulated as a constrained optimization problem [4,10,11,12]. The objective function considered is production cost or production rate or a suitable combination of them for optimization by treating all the variables as deterministic. The constraint set includes bounds on cutting parameters as well as restrictions on the cutting force developed, cutting power required and surface finish.

Objective functions

Cost of production per piece

The cost of production per piece $F_1(X)$ consists of the machining cost, tool cost, tool changing cost and a handling cost.

$$F_1(X) = C_m\, n\, t_c + \frac{n\, t_c}{T_1} C_t + \frac{n\, t_c}{T_1} t_{ch}\, C_m$$

where,

C_m = Machining cost.

C_t = Tool cost (cost per edge).

t_c = Cutting time.

n = Number of passes.

T_1 = Tool life.

t_{ch} = Tool change time.

X is the vector of cutting parameters given by

$$X = \begin{Bmatrix} V \\ f \\ d \end{Bmatrix} .$$

The expression for t_c for various operations is given in Table II.1.

Production Rate

The total time required to produce a piece is the sum of machining time and the tool changining time. Time required per piece is

$$n\ t_c + \frac{n\ t_c}{T_1}\ t_{ch}$$

The expression for production rate is given by

$$F_2(X) = \frac{1}{n\ t_c + \dfrac{n\ t_c}{T_1}\ t_{ch}}$$

So the objective function can be minimizing production cost $F_1(X)$ or maximizing production rate $F_2(X)$ or suitable combination of them as minimizing

$$a.F_1(X) + (1-a)/F_2(X)$$

where a is the weightage for production cost and all cases of varying objectives covered if a varies from 0 to 1.

Constraints

For the optimization of the objective function considered, the factors that impose restrictions on the cutting parameters need to be considered. The restrictions come from various considerations like the required surface finish, the availability

of power, the force developed.

Bounds on cutting speed

The lower and upper bounds on the cutting speed are taken as

$$V_l \leq V \leq V_u$$

where V_l and V_u are lower and upper bounds on the speed.

Here the lower bound V_l is provided to avoid the formulation of the built-up edge.

Bounds in feed

The feed is restricted as

$$f_l \leq f \leq f_u$$

where f_l and f_u are lower and upper bounds on the feed rate.

Bounds on depth of cut

The depth of cut is restricted as

$$d_l \leq d \leq d_u$$

where d_l and d_u are lower and upper bounds on depth of cut.

Bounds on the cutting force

It is necessary to put a restriction on the force developed because a higher value of force may produce an excessive deflection of the workpiece and require a larger power for the cutting operation.

$$F \leq F_u$$

The expression for the cutting force for different operations is given in Table II.2.

Constraint on power

The cutting power required is

$$P_c = F_c V$$

The cutting power should not exceed the available power, and thus the constraint becomes

$P_c = \eta_m$ (Power input)

where η_m efficiency of the machine.

2.4.2 Probabilistic Model

As mentioned in the Section 1.5, in most of the metal cutting methods, the coefficients involved in the equations under consideration are treated as deterministic. However, in practice, metal cutting phenomena are mainly probabilistic, and hence the coefficients obtained in the formulations of such phenomena have a probabilistic nature. Typical examples of this include the tool life and cutting force equations which are often considered in establishing an objective function and a constraint respectively. The amount of tool wear varies from tool to tool due to inherent variations in the tool wear mechanism along with experimental variation. Thus, the tool life estimated from tool wear observations should be treated as random instead of deterministic variable. The coefficients in an experimentally determined cutting force equation should also be treated as random variables.

An analytic method, applying a chance constrained programming concept, is used to determine the optimum cutting conditions considering the probabilistic nature of the objective function and constraints [12,14,15]. In the analysis,the random variables are assumed to be indepedent and follow normal distribution. For tool life, probablistic distributions explained in Section 2.2 are used.

Objective Function

If F represents the objective function in terms of random variables z_i , F(Z) can be expanded about the mean values of z_i as

$$F(Z) = F(\overline{Z}) + \sum_i \frac{\partial F}{\partial z_i}\bigg|_{\overline{z}} (z_i - \overline{z}_i) + \text{higher order terms.}$$

$$(2.20)$$

If the standard deviations of z_i are small, $F(Z)$ can be approximated by first two terms of the Eq.(2.20).

$$F(Z) \approx F(\overline{Z}) - \sum_i \frac{\partial F}{\partial z_i}\bigg|_{\overline{z}} \overline{z}_i + \sum_i \frac{\partial F}{\partial z_i}\bigg|_{\overline{z}} z_i = \psi\ (\overline{Z})$$

As all the z_i's are assumed to follow normal distribution, ψ also follows normal distribution. The mean and variance of ψ are given by

$$\overline{\psi} = F\ (\ Z\ )$$

$$\mathrm{Var}(\psi) = \sigma_\psi^2 = \sum_i \left(\frac{\partial F}{\partial z_i}\bigg|_{\overline{z}} \right)^2 \sigma_{z_i}^2$$

Since all z_i's are independent.

For the purpose of optimization, a new objective function F_1 is constructed as

$$F_1 = a_1\ \overline{\psi} + a_2\ \sigma_\psi\ .$$

where a_1 and a_2 are greater than zero and their numerical values indicate the relative importance of $\overline{\psi}$ and σ_ψ.

Constraints

If some parameters are random in nature, the constraints will also be probablistic and if the probability, that a given constraint is satisfied to be greater than a certain value, is known then the constraint can be written as

$$\Pr\ [\ g_j(Z) \le b_j\ ] \ge p_j. \qquad (2.21)$$

Let y_j be new random variable such that

$$y_j = \phi_j(Z) = b_j - g_j(Z),$$

then Eq.(2.21) can be written as

$$\int_0^{\infty} p(y_j)\, dy_j \geq p_j \qquad (2.22)$$

where $p(y_j)$ is the density function of the random variable y_j. By expanding $\phi_j(Z)$ about the mean value z_j and by retaining only the linear terms

$$y_j = \phi_j(Z) \approx \phi_j(\overline{Z}) + \sum \frac{\partial \phi_j}{\partial z_j}\bigg|_{\overline{Z}} (z_i - \overline{z}_i)$$

Here y_j is a normally distributed random variable and its mean and standard deviations are given by

$$\overline{y}_j = \phi_j(\overline{Z})$$

and

$$\sigma_{y_j} = \left[\sum_i \left(\frac{\partial \phi}{\partial z_i}\bigg|_{\overline{z}} \right)^2 \sigma_{z_i}^2 \right]^{1/2}$$

with the transformation variable as

$$\theta = (y_j - \overline{y}_j) / \sigma_{y_j}$$

Since

$$\int_{-\infty}^{\infty} 1/\sqrt{2\pi} \quad e^{-t^2/2} \quad dt = 1$$

Eq.(2.20) becomes

$$\int_{-\left(\frac{\overline{y}_j}{\sigma_{y_j}} \right)}^{\infty} 1/\sqrt{2\pi} \quad e^{-\theta^2/2} \quad d\theta \geq \int_{\psi(p_j)}^{\infty} 1/\sqrt{2\pi} \quad e^{-t^2/2} \quad dt$$

where $\psi(p_j)$ depends upon the probability level p_j. Thus

$$- \frac{\bar{y}_j}{\sigma_{y_j}} \leq \psi\,(p_j)$$

i.e.,

$$- \bar{y}_j - \psi\,(p_j)\,\sigma_{y_j} \leq 0$$

$$g_j\,(\,\bar{Z}\,) - \psi\,(p\,) \left[\sum_i \left(\frac{\partial \phi}{\partial z_i} \bigg|_{\bar{z}} \right)^2 \sigma^2_{z_i} \right]^{1/2} \leq \bar{b}_j\ .$$

Thus, the optimization problem can be stated in its equivalent deterministic form as

Minimize $F_1 = a_1\,\bar{\psi} + a_2\,\sigma_\psi$, a_1 and $a_2 > 0$

subject to constraints

$$g_j(\bar{Z}) - \psi(p_j) \left[\sum \left(\frac{\partial \phi}{\partial z_j} \bigg|_{\bar{Z}} \right)^2 \sigma^2_{x_i} \right] \leq \bar{b}_j,$$

$$j = 1,\ 2,\ \ldots\ldots,\ m.$$

2.5 Solution Procedure used for Optimization

The Optimization problem formulated in the previous section is a nonlinear constrained problem. The objective function is in terms of cutting time and tool life. The cutting time for various oerations is given Table II.1. The cutting time in tern is a function of speed, feed rate, depth of cut etc. Tool life is calculated as explained in Section 2.3.

This program is solved by Sequentially Unconstrained Minimizaion Technique (SUMT) [23], described briefly in Appendex A. In SUMT, first the optimization problem is converted to unconstrained otimization problem by adding penalities when the

constraint is violated. For solving unconstrained problem, David-Fletcher-Powell method (DFPM) is used. For minimizing step length in DFPM, qudratic interpolation method is used.

TABLE II.1

List of cutting time formulae for various operations.

Operation Name	Cutting time (Sec)	
Turning, Boring, Thread cutting	$\dfrac{\Pi\ D\ L}{V\ f}$	*
Facing	$\dfrac{60\ L}{N\ f}$	
Taper turning	$\dfrac{\Pi\ D\ D_c\ (D_c+d)}{2\ V\ f\ Sin(\phi)\ d}$	
Planing, Shaping	$\dfrac{1.6\ W\ StLen}{V\ f}$	
Slotting	$\dfrac{2\ W\ StLen}{V\ f}$	
Milling	$\dfrac{(1.2)\ 60\ L}{N\ f_t\ Z}$	#
Drilling, Reaming	$\dfrac{60\ L}{N\ f}$	&

* Ermer [7]

Field [11]

& Wysk [28]

TABLE II.2

Operation Name	Force (Kg)	Surface finish (μm)
Turning, Boring * Taper turning Thread cutting	$\frac{\sqrt{2}\ YS\ f\ d}{\sin \beta}$	$\frac{1473000}{V^{1.52}\ d^{0.25}\ f}$
Facing %	$F_c = \frac{13680.2\ f^{0.1}}{V^{0.89}\ N^{0.1}}$ $F_t = \frac{24212.68\ f^{0.1}}{V^{0.774}\ N^{0.32}}$	(Same as Turning)
Planing, Shaping Slotting	(Same as Turning)	(Same as Turning)
Peripheral @ milling	$\frac{140\ W\ f^{0.72}\ d^{0.86}\ Z}{\pi\ (2\ R)^{0.86}}$	$\frac{250000\ f^2}{4\ R}$
Face milling @	$95(2R)\ d^{0.76}\ f^{0.97}\ \sum_{i=1}^{Z} \sin^{0.97}(\psi_i)$	$\frac{250000\ f^2}{4\ R}$
Drilling, & Reaming	$0.195\ BHN\ f^{0.8}\ d_i^{0.8} + 0.0022\ BHN\ d_i^2$	Torque(Kg-mm) = $0.087\ BHN\ f^{0.8}\ d_i^{1.8}$

@ Bhattacharya [2]

% Chitta [4]

* Ermer [7]

& Wysk [28]

Notations used in Table II.1 and Table II.2

V	-	Velocity of Cutting (mm/sec)
N	=	Rpm
f	=	Feed rate (mm/rev)
f_t	=	feed rate per tooth (mm)
d	=	Depth of cut (mm)
L	=	Length to be cut (mm)
D	=	Diameter of the shaft (mm)
D_c	=	Total depth to be removed (mm)
W	=	Width of work piece (mm)
R	=	Radius of cutter (mm)
d_i	=	Diameter of hole (mm)
StLen	=	Stroke length (mm)
YS	=	Yield shear stress (Kg/mm^2)
BHN	=	Brinell hardness number
β	=	Rake angle (rad)
ψ_i	=	Engagement angle of teeth (rad)
ϕ	=	Semi taper angle (rad)
Z	=	Number of teeth in cutter

CHAPTER III

TOOL CONTROL

3.1 Introduction

The tool control system [3] involves a broad spectrum of functions including selection of suppliers, tool-crib management, control of tool delivery system, and tool wear or breakage sensing at the machine tool. The design of tool control calls for minimization of the stocks, i.e., the manufacturing system will yield relatively frequent inventory turnover of smaller sizes.

3.2 Tool Control System

A computerized tool control system is used to ensure the availability of right tools when needed. The system updates tool inventory, tool storage locations, tool crib, tools at machine etc. When a particular tool or set of tools is required, tool control program scans the tool storage data files to ensure the availability of necessary tools and gives the information and description of tools in demand. It can generate the procurement report, regrinding report, scrap report, requirement report etc. and can also give tool status reports. An elaborate database, which includes information on tool codes, useful tool life, capacity of tool magazines, supplier information and machine tool information, is developed.

3.3 Strategies of Tool Control

The tool control system must deal with the following issues [6].

1. Ensuring that appropriate tools, in useable condition, are available at the machine when needed.
2. Transporting tools to and from the machines safely and reliably.
3. Keeping track of tool usage and effecting tool changes when necessary.
4. Maintaining dynamic inventory of all tools in the system, their type, size, number and condition.
5. Monitoring tool inventory levels and initiating orders to replenish tool supply when needed.
6. Keeping the time spent waiting for tools or changing tools to a minimum.

The control system is designed to collect and keep track of the changing condition of the tools, as their usage progresses, i.e., the tool life monitoring. The system consists of the following subsystems.

3.3.1 Tool Crib system

It is designed to handle the tools from time of arrival at the plant, store, retrieve and prepare them for the designated operations (presetting). The crib system contains several units in order to fulfill it's designated tasks.

(i) Reconditioning and disposal

The unit inspects the tool as they arrive and updates their usage and also checks the life left for each tool. The tool is sent for regrinding when the tool becomes blunt i.e., not able to cut. If the tool life is over i.e., the number of regrinds left is zero then it is scraped.

(ii) Tool requistion unit

This unit's task is to issue the tools requistion which will consist of the following items.

(a) Classification system

The classification will cover size, geometry, tool material, insert etc. It will also cover sizes of tool holder, diameter etc.

(b) Availability of stock in the crib

The crib database will follow the inventory at all times.

3.3.2. Tool Inventory

Large inventories tie up large sums of money. It is only material that one should optimize the quantities (of tools in the current case), stored. In order to achieve this optimization, database needs access to the following information.

(i) Tool grouping

All similar operations should be analyzed and identical tools will be grouped together.

(ii) Tool life

The expected tool life in the various operations must be obtained.

3.4 Classification of Tool Information

In the tool database, whole information can be broadly clasified into two specific groups. They are

a. Tool description

Supplier information.

Tool identifier code and name.

Tool type, type of tool holder,clamping devices or tool assembly.

Total number of available tools of each type.

Tool geometry - shape, cutting edges, angles etc.

Tool size - standard or nonstandard.

Characteristics of cutting edge(s).

Tool compensation data - diameter, length.

b. Tool status

Tool wear data.

Useful tool life.

Accumulated tool usage expressed in appropriate tool life units.

Total number of remaining tools of given type.

Total number of broken tools.

Tool regrinding data.

While tool description data remains the same, the information indicating the current tool status is updated continuously. Other tool related variables may be added to the tool database.

3.5 Advantages of Tool Database

The benefits of setting up and using a structured tool database can be summerized as follows.

1. Minimizes tool redundency.
2. Increases tool modularity and promotes universality and standardization.
3. Increases the effectiveness of tool data monitoring and management systems.
4. Improves tool inventory control and rationalizes tool utilization.
5. Provides valuable records of tool data for use in report generation.

3.6 Tool Reports

The tool control system generates the following reports

(i) Tool requirement report

For a given batch size and the corresponding schedule, the total required number of tools of each type are computed.

(ii) Tool loading report

This report indicates the operations and their sequence each tool has to perform on various machine tools.

(iii) Tool procurement report

This report tells which tools are to be procured with the supplier name/code.

(iv) Tool regrinding report

This report gives the regrinding schedule for all tools.

(v) Tool scrap report

It maintains the record of all the tools which are obsolate or whose life is over.

(vi) Tool and machine utilizaton report

This report indicates the utilization of cutting and machine tools. It serves a very useful purpose of evaluation and measurement of productivity in production shop.

Apart from the above reports, tool control system provides the following tool status reports.

(i) Status of particular tool.

(ii) Status of a set of tools.

(iii) Status of a type of tools.

(iv) Tools in stock.

(v) Tools at particular machine.

(vi) Tools at regrinding centre.

CHAPTER IV

IMPLEMENTATION

4.1 Details of System Code

For tool planning part i.e., optimum selection of cutting and machine tools and finding optimal cutting parameters, the Turbo Pascal Version 3.01 is used and implemented on PC XT/AT. Pascal is structured language and has strong data structures. These features of Pascal dominate other programming languages like Fortran, Basic etc. Long programs can be understood and debugged easily. Even though the "goto" command is available in Pascal, it is not used - for making the program readable and easily understandable. Since the optimization problem, discussed in the Section 2.4, is solved iteratively for finding optimum parameters, the facility of running the Pascal program on Disk Operating System (DOS) without using Turbo Pascal system files makes the program efficient and fast, which is very much desirable in the present program. The handling of the data files in this program is very less i.e.,it reads the data only once from data files each time it is executed. In the tool planning program, there is no screen design, no report generation so the dBase is not suited for this program. So the dBase can be ruled out as it is efficient in data processing rather than ececuting the iterative type of programs like optimization. The Basic has got interpreter which executes the commands line by line but the Pascal has the compilier which takes

16 lines of a program at a time.

For the tool control part, the relationl database is used and implemented using dBase III plus on PC XT/AT. In tool control system, lot of data handling is involved i.e., updating, monitoring, transfering of data items rather than manupulating it. Since the database is designed to third normal form, the number of data files have increased. Many reports are generated in tool control program, for which screen design is important. In these cases dBase dominates any other programming languages. The following special features of dBase provide an edge over other programming languages like Pascal, Basic etc.

1. Programs and data are largely independent of each other. The user can change the structure of the database without making many program changes.

2. The in built capability of add, edit, delete, sort, index using a minimum of programming is very much suited for database designs like tool control, where many data files are used.

3. The report generating facility of dBase can be used to quickly create many reports like tool status reports and tool control reports from data files, using, as necessary, mathematical operations.

4. In generating report, many of the data files are to be consulted simultaneously e.g., for procurement report, supplier code is taken from TLSUP data file, supplier name is taken from SUPLIST data file, tool name from TOOL_INF data file, tool usage from TOOL_ST data file. In dBase, maximum of 10 data files can be opened at a time. This facility is very much useful in generating

reports of above mentioned type.

4.2 Design Features

4.2.1 Tool Planning

Program Description

The flow chart of the tool planning program is attached in Appendix B. This program selects the cutting and machine tool from given set optimizing the objective function and also gives optimum cutting parameters. The inputs to this program are operations list, technologically feasible machine and cutting tools for each operation, workpiece and machining details. This program optimizes each operation, taking into account all the combination of machine and cutting tools selected for that operation, by taking workpiece and machining description from input data file, machine and tool data from machine data file and tool data file. The results of all the operations are stored in a data file defined by user. For each operation, the program gives optimum cutting parameters for all the combination of machine and cutting tool. The operations supported are turning, boring, facing, taper turning, thread cutting, planing, shaping, slotting, peripheral milling, face milling, drilling and reaming.

The program is menu driven and can be run as many times as the user wants by selecting any of the data files but input data file and operation data file should have the same number of operations with matching operation numbers. There is a provision to create all data files, edit data records of any files, browse the data files, delete the records, append the records etc. The results of tool planning program are given in Appendix D.

Data File Description

There are five data files; machine data file, tool data file, operation data file, input data file and result data file.

Machine data file

It contains machine tool information. The structure of machine data file is :

machine code, minimum RPM, maximum RPM, tool change time (mean and standard deviation), machining cost (mean and standard deviation), upper bounds on force (mean and standard deviation), surface finish (mean and standard deviation), speed (mean and standard deviation), feed rate, depth of cut etc.

Tool data file

It contains tool information. The structure of tool data file is:

tool code, tool cost (mean and standard deviation), progressive wear (mean and standard deviation), failure rate, rake angle and friction angle (for turning, shaping tool etc.), number of flutes and cutter diameter (for drilling, reaming tool etc.), number of teeth, cutter radius (for milling tool).

Operation data file

It contains the information about operations to be performed. Its structure is

operation code, machine codes, tool codes.

Input data file

It contains machining details. Its structure is :

operation code, weightage to production cost, work piece machining features such as length, width/diameter etc., work piece

characteristics like yield sheer stress/Brinell hardness number etc., weightages to mean, and standard deviation of objective function, probability level of constraints etc., if probabilistic case is considered for all the operations.

Result data file

It gives output information. Its structure is: machine tool code and cutting tool code, optimum speed, feed, depth of cut, and force and surface finish in those conditions, machining time, production cost, production rate, number of passes etc,. for all the operations.

Coding System

All machine tool and cutting tool codes are of three digit numerical code. The first digit indicates whether it is tool code (1) or machine code (2).The second and third digit indicates type of tool/machine :

00 to 09 Turning

10 to 19 Planing, Shaping

20 to 29 Slotting

30 to 39 Drilling, Reaming

40 to 49 Boring

50 to 59 Milling.

The operation code is also numeric and 1 to 12 for various operations as following :

1 Turning

2 Boring

3 Facing

4 Taper turning

5 Thread cutting

6 Planing

7 Shaping

8 Slotting

9 Peripheral milling

10 Face milling

11 Drilling

12 Reaming.

Limitations of the System

For random number generation in finding mean and standard deviation of tool life, the maximum integer value could be used is 32767, because of the Turbo Pascal system limitation.

In the Eq. (2.5) and Eq. (2.13) for determining e^{-y^2} the value of y can not be more than ± 9, because if the value of y exceeds the value of e^{-y^2} goes out of bound maximum real value ($0.2*10^{38}$) defined by Turbo Pascal.

In this programme, for any operation, the maximum of 10 tool codes and the maximum of 5 machine codes can be given. The program will become very slow if higher number of tool codes or machine codes are given, so at first level itself, the tool which can not be optimum should be eliminated by experience or from the cost of tool or cost of machining.

4.2.2 Tool Control

Program Description

As discussed in the previous chapter, the tool control program can generate the real-time reports and tool status

reports.The flow chart of this program is attached in Appendix C. Inputs to this program are

1. The job schedule giving the job and operation sequence on the machine along with the start and finish times.

2. The type of operation

3. Tool material.

This program is also menu driven and there are three menus.

1. Create and edit data file menu

In this menu options for creating new machine and cutting tool files are available. There is also a facility to edit any data file i.e. append, delete, browse etc.

2. Real-time report menu

All the real-time reports, discussed in Section 3.6 can be generated.

3. Tool status reports

This gives status of all the tools for the required need.

Design Issues

The basic design issues involved in designing of database file are

Minimum repetition of data

File integrity

Quick accessibility

Optimum data file size

Optimum number of files

Minimum data repetition saves space for data storage.

Validity and integrity of data is maintained by minimum repetition of data. Because if, data is to be edited then it has

to be changed at all the places whereever it occurs and this process is prone to mistake. Quick accessibility of data makes operation of data searching fast. We should make a compromise between large size of file and too many files because in both the cases, the operation becomes slow. Data is accessed through files indexed on a key field or a foreign key. All the data files are normalized to third normal form. Normalization of data is the process by which data elements are organized in a fashion optimized to produce as stable a data structure as possible. Data changed in third normal form is most practical and is often presumed to be in stable form.

Coding System

Same Coding system is followed as discussed in the tool planning program.

User Manual

The user manual is attached in Appendix E.

CHAPTER V

CONCLUSIONS AND SCOPE FOR FURTHER WORK

5.1 Conclusions

In the present work undertaken for developing managemnt information system for tool planning and control, a general framework of tool information system is implemented on PC XT/AT.

For tool planning, considering both deterministic and probabilistic cases, machine tool and cutting tool combination is selected based on optimum object function. Main emphasis is given to tool life, which is probabilistic in nature. Attempts are made to use the tool life distribution in optimization of machining parameters which may give more realistic results.

In tool control, the various reports like tool scheduling report, tool regrinding report, tool procurement report, tool utilization report and machine utilization report are generated which can be used in any manufacturing system such as tool maintenance, tool stock control, process control, production and process planning etc.

For a given tool, or a set of tools, or a type of tools the system provides the information about the status of tool(s) specifying whether in operation on a machine, in stock or at the regrinding centre. It also provides the information with full details about all the tools available on a machine, in stock or at the regrinding centre.

For both tool planning and control, creating and editing i.e. updating, browsing, deleting, editing particular field of record of any data file are provided.

The above two modules tool planning and control are connected by batch files.

5.2 Scope for Further Work

The data files of the two modules can be integrated by ASCII code. To make the tool planning more versatile, the other operations can also be added. Here selecting the technological feasible machine and cutting tools are not considered. So this also can be added as an extension to this work. In tool control module, the R-r policy or S-s policy or any other suitable policy of inventory control can be implemented for procurement of tools.

REFERENCES

1. Abuelnaga A.M.,El-Dardiry M.A., Optimization Models for Metal Cutting, International Journal of Machine Tool Design and Research, Vol. 24, No. 1, 1984, pp 11.

2. Bhattacharyya A., Metal Cutting - Theory and Practice, Central Book Publishers, Calcutta, 1984.

3. Ber A., Falkenburg D.R., Tool Management for FMS, Annals of CIRP, Vol. 34, No. 1, 1985, pp 387.

4. Chitta A.K., A Decision Support System for Process Planning, M.Tech. Thesis, Indian Institute of Technology, Kanpur, 1987.

5. Davis B.G., Olson M.H., Management Information System, McGraw-Hill Book Company, 1984.

6. ElMaraghy H.A., Automated Tool Management in Flexible Manufacturin , Journal of Manufacturing Science, Vol. 4, No. 1, pp 1.

7. Ermer D.S., Kromodiharddjo, Optimization of Multipass Turning with Constraints, ASME, Journal of Engineering for Industry, Vol. 103, No. 4, 1981, pp 462.

8. Ermer D.S., Optimization of the Constrained Machining Economics Problems by Geometric Programming, ASME, Journal of Engineering for Industry, Vol. 93, 1971, pp 1067.

9. Fenton R.G., Joseph N.D., The effects of the Statistical nature of tool-life on Economics of Machining, International Journal of Machine Tool Design and Research, Vol. 19, No. 1, 1979, pp 43.

10. Field M., Zlatin N., Williams R., Kronenberg M., Computerized determination and Analysis of Cost and Production Rates for Machining Operations: Part 1 - Turning, ASME, Journal of Engineering for Industry, Vol. 90, No. 3, 1968, pp 455.

11. Field M., Zlatin N., Williams R., Kronenberg M., Computerized Determination and Analysis of Cost and Production Rates for Machining Operations: Part 2 - Milling, Reaming, Taping, ASME, Journal of Engineering for Industry, Vol. 91, No. 3, 1969, pp 585.

12. Hati S.K., Rao S.S., Determination of Optimum machining Conditions - Deterministic and Probabilistic approaches, ASME, Journal of Engineering for Industry, Vol. 98, No. 1, 1976, pp 354.

13. Imo I.I., Leech D.J., Discontinuous Optimization in Batch Production using SUMT, International Journal of Production Reasearch, Vol. 22, No. 2, 1984, pp 313.

14. Iwata K., Murotsu Y., Iwatsubo T., Fujii S., A Probabilistic Approach to the Determination of the Optimum Cutting Conditions, ASME, Journal of Engineering for Industry, Vol. 94, No. 4, 1972, pp 1099.

15. Iwata K., Murotsu Y., Oba F., Optimization of Cutting Conditions for Multipass Operations considering Probabilistic nature in Machining Processes, ASME, Journal of Engineering for Industry, Vol. 99, 1977, pp 210.

16. McCartny J., Hinds B.K., Tooling Economics in Integrated Manufacturing Systems, International Journal Of Production Research, Vol. 20, No. 4, 1982, pp 493.

17. National Twist Drill & Tool Co., Winter Bros Co., Metal Cuttings, Rochester, Mich., April 1959.

18. Ramalingam S., Watson J.D., Tool-life Distributions - Part 1: Single-Injury Tool Life Model, ASME, Journal of Engineering for Industry, Vol. 99, No. 3, 1977, pp 519.

19. Ramalingam S., Watson J.D., Tool-life Distributions - Part 2: Multiple-Injury Tool Life Model, ASME, Journal of Engineering for Industry, Vol. 99, No. 3, 1977, pp 523.

20. Rao S.S., Hati S.K., Compuerized Selection of Optimum Machining Conditions for a Job requiring Multiple Operations, ASME, Journal of Engineering for Industry, Vol. 100, No. 1, 1978, pp 356.

21. Rao S.S., Optimization Theory and Applications, Wiley Eastern Limited, 1978.

22. Rossetto S., Levi R.,Fracture and Wear as factors Affecting Stochastic Tool-Life Models and Machining Economics, ASME, Journal of Engineering for Industry, Vol. 99, 1977, pp 281.

23. Rossetto S., Zompi A., A Stochastic tool-life Model, ASME, Journal of Engineering for Industry, Vol. 103, No. 1, 1981, pp 126.

24. Schmidt A.O., Heat in Metal Cutting, Machining Theory and Practice, ASM, Cleveland, Ohio, 1950.

25. Shanker K., Gopinath B.V., Design and Development of a Database for Tool Planning and Control, 12th All India Machine Tool Design and Research Conference, IIT Delhi, 1986.

26. Wager J.G., Barash M.M., Study of the distribution of the life of HSS Tools, ASME, Journal of Engineering for Industry, Vol. 93, 1971, pp 1044.

27. Wu S.M., Ermer D.S., Maximum Profit as Criterion in the Determination of the Optimum Cutting Conditions, ASME, Journal of Engineering for Industry, Vol. 88, No. 4, 1966, pp 435.

28. Wysk R.A., Davis P.R., Tanchoco J.M.A., Machining Parameter Optimization with lot size considerations, AIIE Trans, Vol. 12, No. 1, 1980, pp 59.

29. Zompi A., Levi R., Tool Life distributions in Process Optimization, CIRP Annals, Vol. 28, No. 1, 1979, pp 371.

APPENDIX A

Solution Procedure used for Optimization

The constrained optimization problem stated in Section 2.4 is solved by using Sequential Unconstrained Minimization Technique (SUMT), flow chart of which is given in Fig. A-1. In this method, the objective function $f(X)$ is transformed by adding severe penality to it whenever a constraint is violated in such a way that the unconstrained optimization technique is forced to find the minimum in the feasible region. In this case, solution is found as the limit of a sequence of solutions to suitably transformed problems. The computational procedure is given as follows:

1. Start with an initial feasible vector X_0, which satisfies all the constraints as $g_j\ (X) \le 0$.
2. Find the unconstrained minimum X_1^* of a new function $\phi(\ X,\ r_1\ )$ defined by

$$\phi\ (\ X,\ r_1\ ) = f(X) - r_1 \sum_{j=1}^{m} \frac{1}{g_j(X)}$$

for any $r_1 > 0$.

3. Starting from X_{k-1}^*, repeat step 2 and find the minimum X_k^* of

$\phi\ (\ X,\ r_k\ ) =$ for any $r_1 > 0$.

4. Finally as $k \rightarrow \infty$, the solution X_k^* can be taken as the solution of the original problem stated.

For the unconstrained minimization of $\phi\ (\ X,\ r_k\ )$, the method of David-Fletcher-Powel, is used and the flow chart is

given in Fig. A-2. This method is described by following steps :

(i) Starting with positive definite matrix $[H_{i-1}]$ and an initial point X_{i-1}, compute the search direction d_i for minimization as (i=1, to start with)

$$d_i = -[H_{i-1}]\nabla\phi_{i-1}$$

$$= -[H_{i-1}]\nabla\phi(X_{i-1}).$$

(ii) Compute the step length λ_i to minimize $\phi(X_{i-1}+\lambda_i d_i)$.

(iii) Find a new estimate for the optimum point as

$$X_i = X_{i-1} + \lambda_i d_i$$

and test whether X_i satisfies the prescribed convergence criteria.

(iv) Update the matrix $[H_i]$ as

$$[H_i] = [H_{i-1}] + \lambda_i \frac{d_i\, d_i^T}{\nabla\phi_i^T\, [H_{i-1}]\, \nabla\phi_i}$$

$$- \frac{[H_{i-1}](\nabla\phi_i - \nabla\phi_{i-1})(\nabla\phi_i - \nabla\phi_{i-1})^T [H_{i-1}]^T}{(\nabla\phi_i - \nabla\phi_{i-1})^T [H_{i-1}] (\nabla\phi_i - \nabla\phi_{i-1})}$$

and repeat steps (i) through (iv) with i=i+1, until the stated convergence is achieved in step (iii).

For finding the minimum step length λ_i in step (ii), quadratic interpolation method, flow chart is shown in Fig. A-3, is used. This method finds the minimizing step length λ^* in two stages. In the first stageS-vector is normalized so that a step length of $\lambda = 1$ is acceptable. In second stage, the function $f(\lambda)$ is approximated by quadratic function $h(\lambda)$ and the minimum, λ^*, of

$h(\lambda)$ is found. If $\tilde{\lambda}^*$ is not sufficiently closer to the true minimum λ^*, the third stage is used. In this stage, a new quadratic function $h'(\lambda) = a' + b'\lambda + c'\lambda^2$ is used to approximate $f(\lambda)$, and a new value of $\tilde{\lambda}^*$ is found. This procedure is continued until $\tilde{\lambda}^*$, which is sufficiently close to λ^* is found.

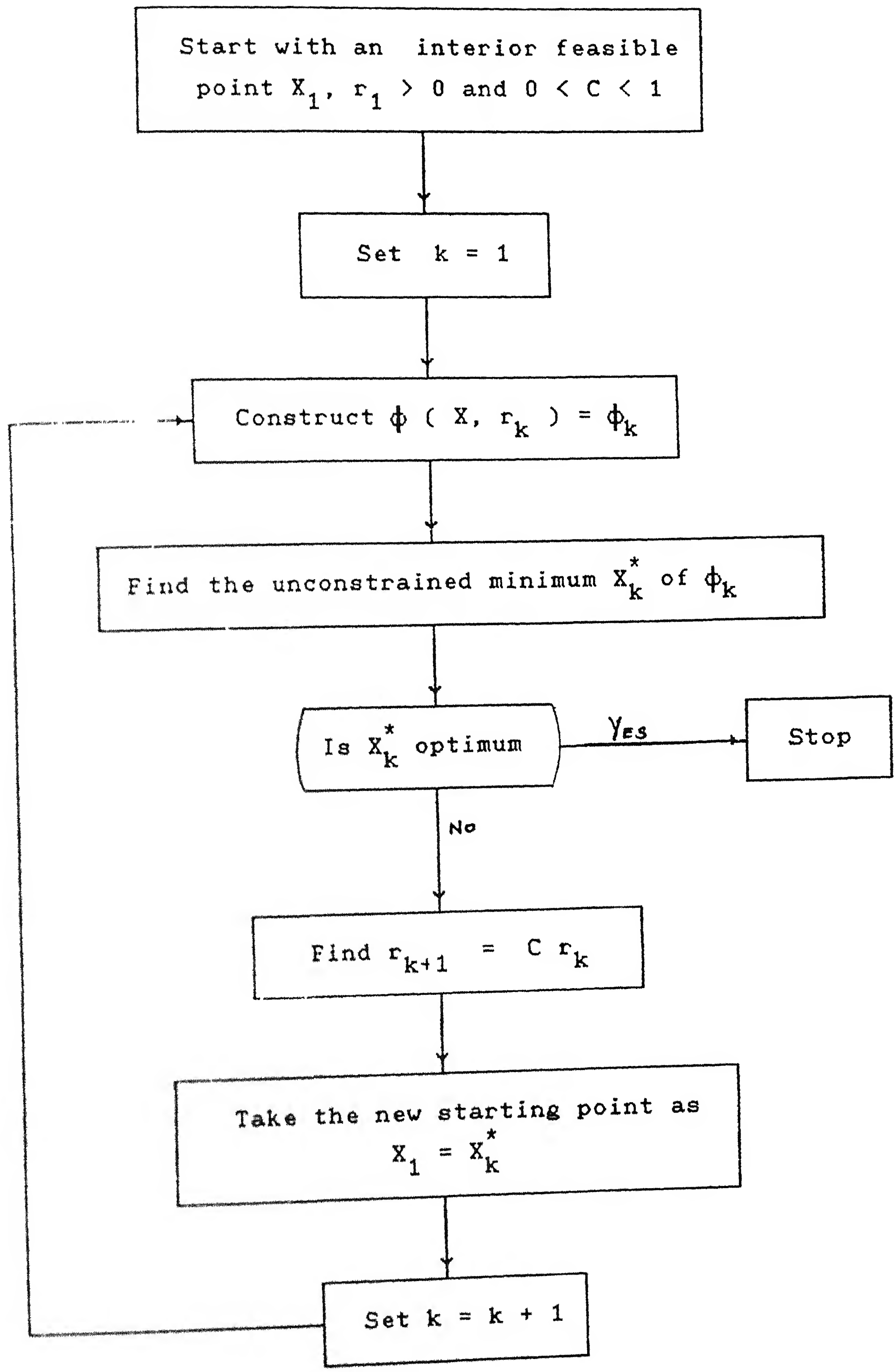

Fig. A - 1. Flow chart for interior penalty method.

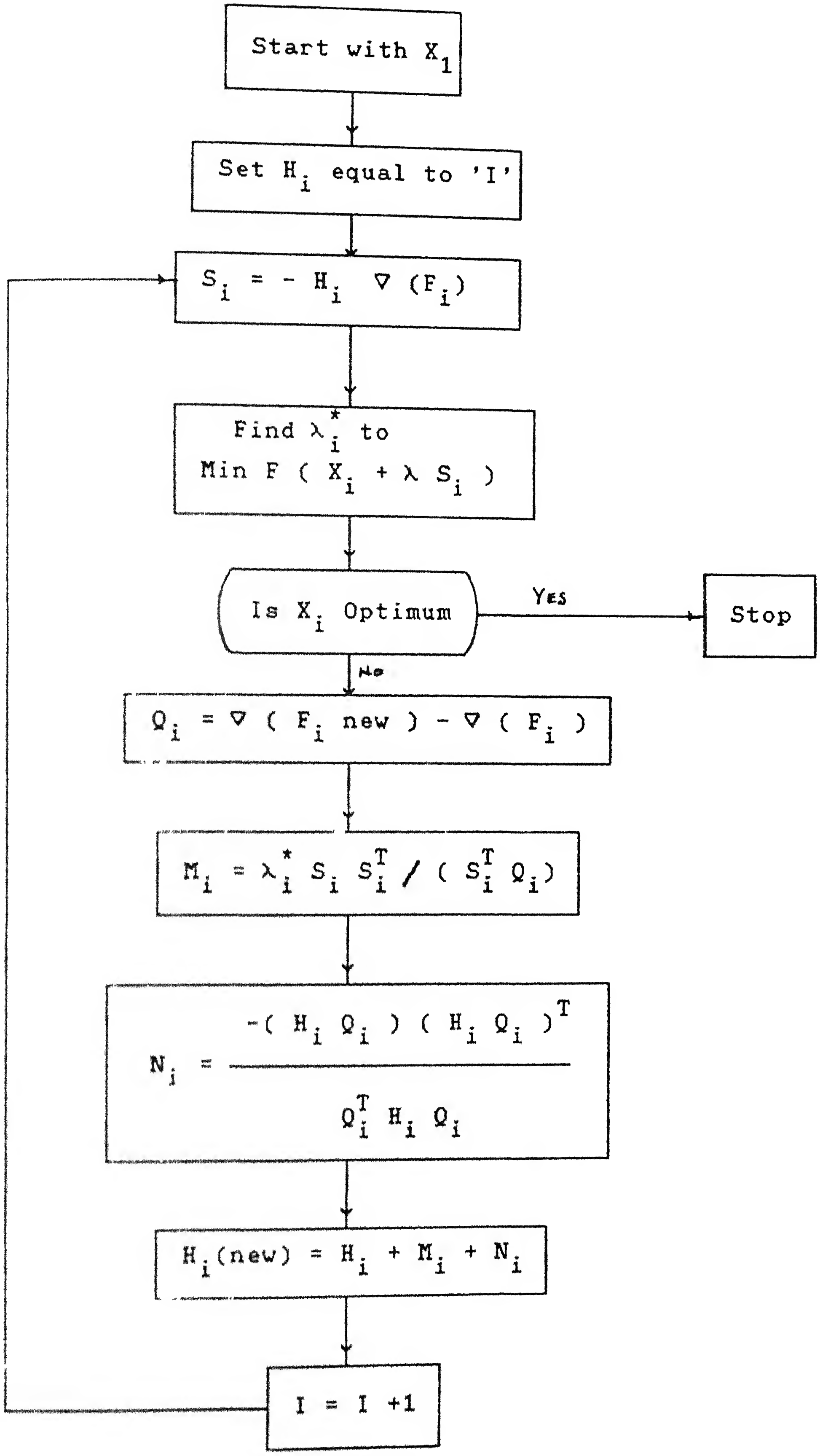

Fig. A - 2. Flow chart for Davidon-Fletcher-powell method

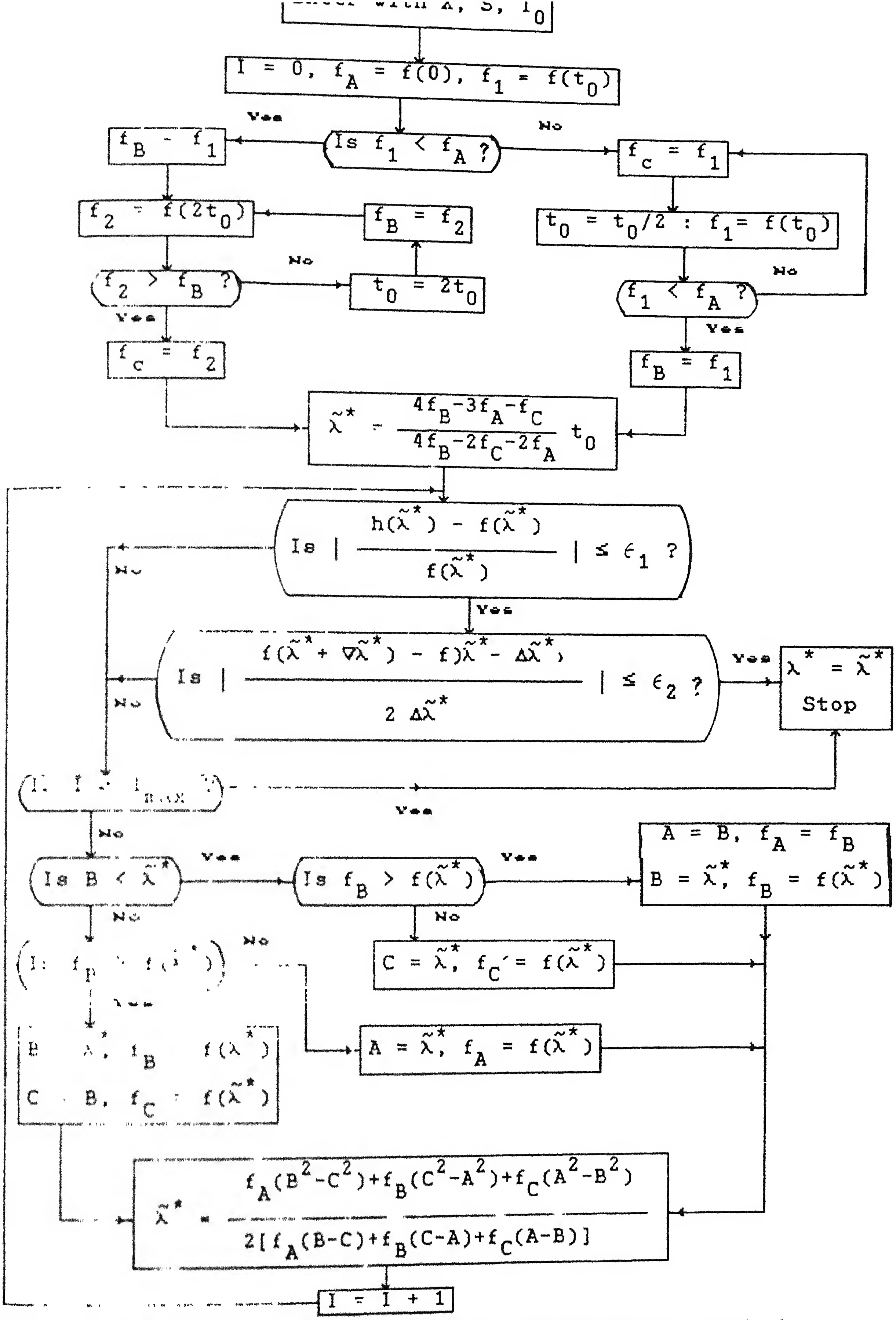

Fig. A - 3 Flow chart for quadratic interpolation method

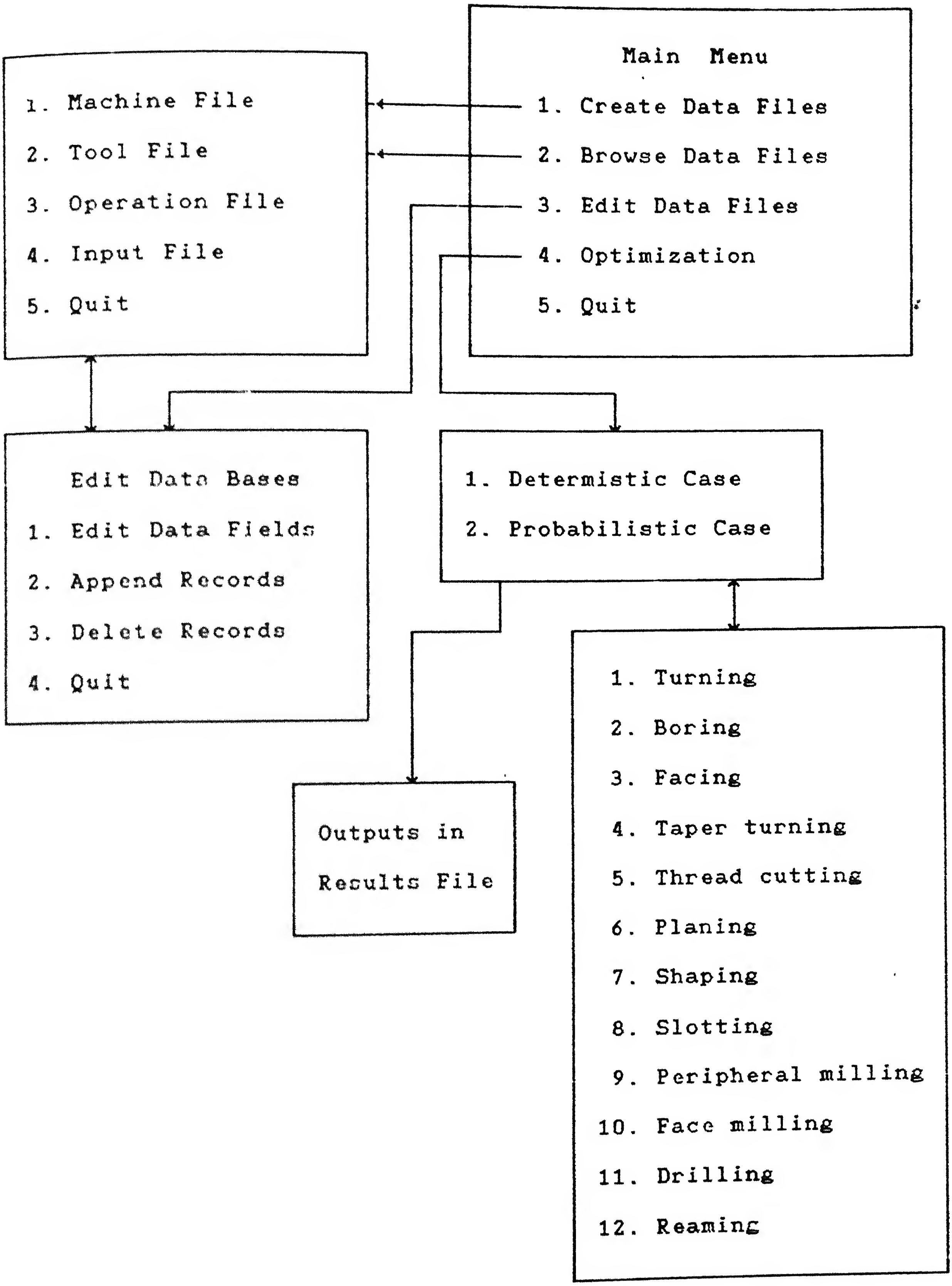

Fig. B - 1. Menu Displays of Tool Planing Program.

APPENDIX D

RESULTS OF TOOL PLANNING PROGRAM

What is the Operation File Name ? turo.dat

* Operation File *

Op No	Op Code	No Of Tools	No Of M/cs	Machine Codes	Tool Codes
1	1	2	2	201 202	101 102

* Input Data *

Operation Number : 1

Operation Code	:	1
Weightage for Production Cost (0-1)	:	0.300
Length of the portion to be turned mm	:	100.0
Initial diameter of the Workpiece mm	:	30.0
Final diameter of the Workpiece mm	:	25.0
Average Loading and Unloading time	:	40.0
Average Yield Shear Stress of the Workpiece Kg/mm2	:	25.0
Variance of Yield Shear Stress of the Workpiece	:	0.8
Weightage to mean of objective function	:	0.500
Weightage to S.D. of objective function	:	0.600
Probability of satisfying force constraint	:	0.700
Probabilty of satisfying surface finish constraint	:	0.300

What is the Operations file name	?	turo.dat
What is the Machine file name	?	mch.dat
What is the Tool file name	?	tool.dat
What is the Input file name	?	turi.dat
What is the Output file name	?	tur1.dat

Optimum Cutting Conditions for Deterministic Case for the following combination of M/c & Cutting tools

Tool Code	:	101
Machine Code	:	201

Turning Operation

Rpm	:	912.0393
Feed mm	:	0.3286
depth of cut mm	:	0.6467
Number of passes	:	4
Force Kg	:	9.0006
Surface finish um	:	79.7045
Machining Time Sec	:	80.0799
Production Rate Pieces/hr	:	44.9551
Production Cost Rs/piece	:	0.3737
Objective Function	:	0.1277

Optimum Cutting Conditions for Deterministic Case for the following combination of M/c & Cutting tools

Tool Code	:	101
Machine Code	:	202

Turning Operation

Rpm	:	1150.2168
Feed mm	:	0.4121
depth of cut mm	:	0.6919
Number of passes	:	4
Force Kg	:	12.0764
Surface finish um	:	43.9208
Machining Time Sec	:	50.6386
Production Rate Pieces/hr	:	71.0920
Production Cost Rs/piece	:	0.3173
Objective Function	:	0.1050

Optimum Cutting Conditions for Deterministic Case for the following combination of M/c & Cutting tools

Tool Code	:	102
Machine Code	:	201

Turning Operation

Rpm	:	912.0371
Feed mm	:	0.3267
depth of cut mm	:	0.6458
Number of passes	:	4
Force Kg	:	7.6706
Surface finish um	:	80.2027
Machining Time Sec	:	80.5539
Production Rate Pieces/hr	:	44.6906
Production Cost Rs/piece	:	0.3773
Objective Function	:	0.1288

Optimum Cutting Conditions for Deterministic Case for the following combination of M/c & Cutting tools

Tool Code	:	102
Machine Code	:	202

Turning Operation

Rpm	:	1150.0673
Feed mm	:	0.4173
depth of cut mm	:	0.7347
Number of passes	:	4
Force Kg	:	11.1452
Surface finish um	:	42.7419
Machining Time Sec	:	50.0208
Production Rate Pieces/hr	:	71.9701
Production Cost Rs/piece	:	0.3143
Objective Function	:	0.1040

Deterministic Case

The following combination of Cutting Tool and Machine Tool is Optimum for given conditions for the Operation Turning

Tool Code	Machine Code
102	202

Do you want to see the cutting conditions for this combination ? y

Turning Operation

Rpm	:	1150.0673
Feed mm	:	0.4173
depth of cut mm	:	0.7347
Number of passes	:	4
Force Kg	:	11.1452
Sf um	:	42.7419
Machining Time Sec	:	50.0208
Production Rate Pieces/hr	:	71.9701
Production Cost Rs/piece	:	0.3143
Objective Function	:	0.1040

Optimum Cutting Conditions for Probabilistic Case for the following combination of M/c & Cutting tools

Tool Code	:	101
Machine Code	:	201

Turning Operation

Rpm	:	912.0514
Feed mm	:	0.3476
depth of cut mm	:	0.8012
Number of passes	:	4
Force Kg	:	11.7948
Surface finish um	:	71.4242
Machining Time Sec	:	75.7106
Production Rate Pieces/hr	:	47.5495
Production Cost Rs/piece	:	0.3533
Objective Function	:	6.7836

Optimum Cutting Conditions for Probabilistic Case for the following combination of M/c & Cutting tools

Tool Code	:	101
Machine Code	:	202

Turning Operation

Rpm	:	1150.0000
Feed mm	:	0.3108
depth of cut mm	:	0.5925
Number of passes	:	5
Force Kg	:	7.2114
Surface finish um	:	60.2639
Machining Time Sec	:	83.9486
Production Rate Pieces/hr	:	42.8834
Production Cost Rs/piece	:	0.5261
Objective Function	:	6.0216

Optimum Cutting Conditions for Probabilistic Case for the following combination of M/c & Cutting tools

Tool Code	:	102
Machine Code	:	201

Turning Operation

Rpm	:	912.0470
Feed mm	:	0.3435
depth of cut mm	:	0.7992
Number of passes	:	4
Force Kg	:	9.2458
Surface finish um	:	71.7222
Machining Time Sec	:	76.6148
Production Rate Pieces/hr	:	46.9883
Production Cost Rs/piece	:	0.3588
Objective Function	:	6.8525

Optimum Cutting Conditions for Probabilistic Case for the following combination of M/c & Cutting tools

Tool Code	:	102
Machine Code	:	202

Turning Operation

Rpm	:	1150.0000
Feed mm	:	0.3121
depth of cut mm	:	0.5929
Number of passes	:	5
Force Kg	:	6.7277
Surface finish um	:	60.2904
Machining Time Sec	:	83.5838
Production Rate Pieces/hr	:	43.0706
Production Cost Rs/piece	:	0.5252
Objective Function	:	5.9848

Probabilistic Case

The following combination of Cutting Tool and Machine Tool is Optimum for given conditions for the Operation Turning

Tool Code	Machine Code
102	202

Do you want to see the cutting conditions for this combination ? y

Turning Operation

Rpm	:	1150.0000
Feed mm	:	0.3121
depth of cut mm	:	0.5929
Number of passes	:	5
Force Kg	:	6.7277
Sf um	:	60.2904
Machining Time Sec	:	83.5838
Production Rate Pieces/hr	:	43.0706
Production Cost Rs/piece	:	0.5252
Objective Function	:	5.9848

* Operation File *

Op No	Op Code	No Of Tools	No Of M/cs	Machine Codes	Tool Codes
1	8	2	2	221 222	121 122

* Input Data *

Operation Number : 1

Operation Code	:	8
Weightage for Production Cost (0-1)	:	0.400
Length of the slot mm	:	30.0
Width of the slot mm	:	13.0
Depth of the slot mm	:	6.0
Average Loading and Unloading time	:	30.0
Average Yield Shear Stress of the Workpiece Kg/mm2	:	25.0
Variance of Yield Shear Stress of the Workpiece	:	0.4
Weightage to mean of objective function	:	0.300
Weightage to S.D. of objective function	:	0.600
Probability of satisfying force constraint	:	0.500
Probabilty of satisfying surface finish constraint	:	0.500

What is the Operations file name	?	sloto.dat
What is the Machine file name	?	mch.dat
What is the Tool file name	?	tool.dat
What is the Input file name	?	sloti.dat
What is the Output file name	?	slot1.dat

Optimum Cutting Conditions for Deterministic Case for the following combination of M/c & Cutting tools

Tool Code	:	121
Machine Code	:	221

Slotting Operation

Spm	:	72.0000
Feed mm	:	0.3085
depth of cut mm	:	0.2334
Number of passes	:	26
Force Kg	:	2.8621
Surface finish um	:	22.7749
Machining Time Sec	:	18.0003
Production Rate Pieces/hr	:	199.9968
Production Cost Rs/piece	:	0.0523
Objective Function	:	0.0239

Optimum Cutting Conditions for Deterministic Case for the following combination of M/c & Cutting tools

Tool Code	:	121
Machine Code	:	222

Slotting Operation

Spm	:	80.0000
Feed mm	:	0.2339
depth of cut mm	:	0.8617
Number of passes	:	7
Force Kg	:	8.0084
Surface finish um	:	17.5849
Machining Time Sec	:	5.5927
Production Rate Pieces/hr	:	643.6967
Production Cost Rs/piece	:	0.0173
Objective Function	:	0.0079

Optimum Cutting Conditions for Deterministic Case for the following combination of M/c & Cutting tools

Tool Code : 122
Machine Code : 221

Slotting Operation

Spm	:	72.0000
Feed mm	:	0.3018
depth of cut mm	:	0.2262
Number of passes	:	27
Force Kg	:	2.5641
Surface finish um	:	23.4637
Machining Time Sec	:	19.1027
Production Rate Pieces/hr	:	188.4554
Production Cost Rs/piece	:	0.0551
Objective Function	:	0.0252

Optimum Cutting Conditions for Deterministic Case for the following combination of M/c & Cutting tools

Tool Code : 122
Machine Code : 222

Slotting Operation

Spm	:	80.0000
Feed mm	:	0.2392
depth of cut mm	:	0.8631
Number of passes	:	7
Force Kg	:	7.7519
Surface finish um	:	17.1862
Machining Time Sec	:	5.4668
Production Rate Pieces/hr	:	658.5208
Production Cost Rs/piece	:	0.0169
Objective Function	:	0.0077

Deterministic Case

The following combination of Cutting Tool and Machine Tool is Optimum for given conditions for the Operation Slotting

Tool Code	Machine Code
122	222

Do you want to see the cutting conditions for this combination ? y

Slotting Operation

Velocity of cutter	:	80.0000
Feed mm	:	0.2392
depth of cut mm	:	0.8631
Number of passes	:	7
Force Kg	:	7.7519
Sf um	:	17.1862
Machining Time Sec	:	5.4668
Production Rate Pieces/hr	:	658.5208
Production Cost Rs/piece	:	0.0169
Objective Function	:	0.0077

Optimum Cutting Conditions for Probabilistic Case for the following combination of M/c & Cutting tools

Tool Code	:	121
Machine Code	:	221

Slotting Operation

Spm	:	72.0000
Feed mm	:	0.2942
depth of cut mm	:	0.2554
Number of passes	:	24
Force Kg	:	2.9858
Surface finish um	:	23.3545
Machining Time Sec	:	17.4270
Production Rate Pieces/hr	:	206.5758
Production Cost Rs/piece	:	0.0506
Objective Function	:	0.1466

Optimum Cutting Conditions for Probabilistic Case for the following combination of M/c & Cutting tools

Tool Code	:	121
Machine Code	:	222

Slotting Operation

Spm	:	80.0000
Feed mm	:	0.2184
depth of cut mm	:	0.8553
Number of passes	:	8
Force Kg	:	6.9191
Surface finish um	:	17.9667
Machining Time Sec	:	6.8371
Production Rate Pieces/hr	:	526.5360
Production Cost Rs/piece	:	0.0212
Objective Function	:	0.1690

Optimum Cutting Conditions for Probabilistic Case for the following combination of M/c & Cutting tools

Tool Code : 122
Machine Code : 221

Slotting Operation

Spm	: 72.0000
Feed mm	: 0.2877
depth of cut mm	: 0.2486
Number of passes	: 25
Force Kg	: 2.4349
Surface finish um	: 23.3428
Machining Time Sec	: 18.5578
Production Rate Pieces/hr	: 193.9885
Production Cost Rs/piece	: 0.0535
Objective Function	: 0.1490

Optimum Cutting Conditions for Probabilistic Case for the following combination of M/c & Cutting tools

Tool Code : 122
Machine Code : 222

Slotting Operation

Spm	: 80.0000
Feed mm	: 0.2223
depth of cut mm	: 0.8563
Number of passes	: 8
Force Kg	: 6.6451
Surface finish um	: 17.6281
Machining Time Sec	: 6.7151
Production Rate Pieces/hr	: 536.1087
Production Cost Rs/piece	: 0.0207
Objective Function	: 0.1652

Probabilistic Case

The following combination of Cutting Tool and Machine Tool is Optimum for given conditions for the Operation Slotting

Tool Code	Machine Code
121	221

Do you want to see the cutting conditions for this combination ? y

Slotting Operation

Velocity of cutter	:	72.0000
Feed mm	:	0.2942
depth of cut mm	:	0.2554
Number of passes	:	24
Force Kg	:	2.9858
Sf um	:	23.3545
Machining Time Sec	:	17.4270
Production Rate Pieces/hr	:	206.5758
Production Cost Rs/piece	:	0.0506
Objective Function	:	0.1466

REPORTS OF TOOL CONTROL SYSTEM

ENTERING NEW TOOL INFORMATION

TOOL NAME	TURNING	TOOL CODE	106
TOOL MATERIAL	CARBIDE	QUANTITY	2
UNIT PRICE	12.000	TOOL HOLDER CODE	124

STANDARD TOOL CHANGE TIME	12.00
MAXIMUM TOOL LIFE	1000.000
MAXIMUM TOOL WEAR FOR REGRINDING	100.000
MAXIMUM REGRINDINGS POSSIBLE	9

SUPPLIER NAME	WIDID	SUPPLIER CODE	26
REORDER LEVEL	4	LEAD TIME	1.00

ECONOMIC ORDER QUANTITY 5

DO YOU HAVE ANY MORE NEW TOOLS(Y/N) : N

JOB SCHEDULE INPUT

JOB NUMBER	1	MACHINE NUMBER	4
STARTING TIME	20	FINISHING TIME	85
OPERATION NAME		THREADCUTTING	
TOOL MATERIAL		HSS	

ANY MORE OPERATIONS(Y/N) : N

INPUT TO TOOI CONTROL

JOB NUMBER	OPERATION NAME	MACHINE NUMBER	SRARTING TIMF	FINISHING TIME	TOOL MATERIAL
1	TURNING	1	0	50	HSS
1	BORING	2	50	150	CARBIDE
1	FACING	3	200	250	HSS
2	BORING	5	30	140	HSS
2	THREADCUTTING	4	200	275	CARBIDE
2	DRILLING	11	300	330	HSS
3	TAPERTURNING	1	100	200	CARBIDE
3	DRILLING	11	85	95	HSS
3	REAMING	12	100	120	CARBIDE
4	PLANING	6	60	120	HSS
4	FACEMILLING	10	150	230	HSS
5	DRILLING	12	0	27	CARBIDE
5	PERIPHERALMILL	9	150	250	HSS
5	REAMING	12	60	80	CARBIDE

TOOL REQUIREMENT REPORT

TURNING TOOLS
REQUIRED NUMBER 4

TOOL CODES	SERIAL NO
101	1
103	1
101	2
102	1

TOOL REQUIREMENT REPORT

BORING TOOLS
REQUIRED NUMBER 2

TOOL CODES	SERIAL NO
140	1
140	1

TOOL REQUIREMENT REPORT

PLANING/SHAPING TOOLS
REQUIRED NUMBER 1

TOOL CODES	SERIAL NO
110	3

TOOL REQUIREMENT REPORT

SLOTTING TOOLS
REQUIRED NUMBER 0

TOOL REQUIREMENT REPORT

MILLING TOOLS
REQUIRED NUMBER 2

TOOL CODES	SERIAL NO
152	1
153	1

TOOL REQUIREMENT REPORT

DRILLING TOOLS
REQUIRED NUMBER 5

TOOL CODES	SERIAL NO
132	2
132	2
132	1
130	1
130	1

TOOL REQUIREMENT REPOTS

REAMING TOOLS
REQUIRED NUMBER 0

TOOL LOADING REPORT

MACHINE NUMBER 1

TOOL CODE	SERIAL NO	START TIME
101	1	0
102	1	100

TOOL LOADING REPORT

MACHINE NUMBER 2

TOOL CODE	SERIAL NO	START TIME
140	1	50

TOOL LOADING REPORT

MACHINE NUMBER 3

TOOL CODE	SERIAL NO	START TIME
103	1	200

TOOL LOADING REPORT

MACHINE NUMBER 4

TOOL CODE	SERIAL NO	START TIME
101	2	200

TOOL LOADING REPORT

MACHINE NUMBER 5

TOOL CODE	SERIAL NO	START TIME
140	1	30

TOOL LOADING REPORT

MACHINE NUMBER 6

TOOL CODE	SERIAL NO	START TIME
110	3	60

TOOL LOADING REPORT

MACHINE NUMBER 7

TOOL CODE	SERIAL NO	START TIME

TOOL LOADING REPORT

MACHINE NUMBER 8

TOOL CODE	SERIAL NO	START TIME

TOOL LOADING REPORT

MACHINE NUMBER 9

TOOL CODE	SERIAL NO	START TIME
153	1	150

TOOL LOADING REPORT

MACHINE NUMBER 10

TOOL CODE	SERIAL NO	START TIME
152	1	150

TOOL LOADING REPORT

MACHINE NUMBER 11

TOOL CODE	SERIAL NO	START TIME
132	2	85
132	2	300

TOOL LOADING REPORT

MACHINE NUMBER 12

TOOL CODE	SERIAL NO	START TIME
130	1	0
130	1	60
132	1	100

TOOL PROCUREMENT REPORT

TOOL CODE	TOOL_NAME	SUPPLIER	NO_OF_TOOLS
101	TURNING	HMT	10
153	PERIPHERALMILL	HMT	7
111	PLANING	WIDIA	15
130	DRILLING	HMT	13
101	TURNING	SANDWIK	12
111	PLANING	WIDIA	8
103	THREADCUTTING	HMT	14
140	BORING	SANDWIK	10
152	FACEMILLING	HMT	11
121	SLOTTING	SANDWIK	10
102	FACING	WIDIA	12
153	PERIPHERALMILL	SANDWIK	15
102	FACING	SANDWIK	16
110	SHAPING	HMT	10
110	SHAPING	SANDWIK	6

TOOL REGRINDING SCHEDULE

TOOL_ID	SI_NO	TOOL_NAME
101	2	TURNING
102	1	FACING
152	1	FACEMILLING

TOOL SCRAP REPORT

TOOL CODE	SERIAL NO	TOOL NAME	CUMULATIVE LIFE
132	2	DRILLING	500.00
104	1	TURNING	1000.00
112	2	PLANING	408.00
153	3	MILLING	870.00
135	2	REAMING	1200.00
105	1	TURNING	500.00
108	2	TURNING	600.00

MACHINE UTILIZATION REPORT

MACHINE	UTILIZATION
1	0.455
2	0.303
3	0.152
4	0.227
5	0.333
6	0.182
7	0.000
8	0.000
9	0.303
10	0.242
11	0.121
12	0.204

```
        STATUS OF THE TOOL
        PRESS <CR> TO END
      GIVE THE TOOL_ID                 101
      GIVE THE TOOL SERIAL NUMBER        2
```

```
            TOOL NAME                  TURNING
TOOL LIFE LEFT                          500.00
REGRINDINGS LEFT                         12
TOOL WEAR LEFT FOR NEXT REGRINDING       75.00
```

STATUS OF SET OF TOOLS

TOOL_ID	SERIAL_NO	LIFE_LEFT	REGDS_LEFT	WEAR_LEFT
101	1	895.000	9	90.000
101	2	1900.000	17	105.000
102	1	500.000	12	75.000
132	1	900.000	4	160.000
132	2	0.000	0	200.000
111	1	600.000	4	130.000
111	2	100.000	1	100.000
152	1	300.000	3	60.000
152	2	800.000	10	95.000

```
STATUS OF TYPE OF TOOL
PRESS <CR> TO END
GIVE THE TOOL TYPE PLANING
```

```
        TOOL CODE    :  111
        TOOL NAME    :  PLANING

SERIAL_NO  TOOL_LIFE_LEFT  REGDS_LEFT  WEAR_LEFT

    1         600.000          4         130.000
    2         100.000          1         100.000
```

```
            TOOLS IN STOCK

    TOOL_ID     SERIAL NO      TOOL NAME

     153            1           PERIPHERALMILL
     101            2           TURNING
```

PRESS <CR> TO END
GIVE THE LOCATION MACHINE5

TOOLS AT MACHINE5

TOOL_ID	SERIAL NO	TOOL NAME
102	1	FACING
152	1	FACEMILLING

TOOLS AT REGRINDING CENTRE

TOOL_ID	SERIAL NO	TOOL NAME
111	2	PLANING
110	3	SHAPING

APPENDIX E

USER MANUAL

The whole program is divided into two parts. One is Tool Planning and other is Tool Control. After booting the PC XT/AT you get the prompt as

C>   (you are now in C drive of PC)

To change to floppy drive, put the diskette in A drive and type as following

C>A: <CR>   (This takes you to A drive)

Now the prompt is as following

A>   (You are now in A drive)

To start the program type TMIS (Tool Management Information System) and press return as

A>TMIS <CR>

Now, you are in tool planning program. It starts with Main Menu. After creating / selecting data files stored, go for optimization. Then you can choose the deterministic or probabilistic approach for optimization. After processing, the outputs will be stored in results file. You can run this program as many times as you want by selecting each time different data files. To come out of this program select "Quit" from Main Menu. Then it automatically takes you to tool control program. When the prompt (.) comes, it indicates that you are in dBase III+. To start the tool control program, type "Do Main" as follows

.Do Main <CR>

The various real time reports and tool status reports can be selected from sub menus, real time report menu and tool status report menu. To end this program select "Quit" from Main Menu.